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Validation of vortex code viscous models using lidar wake measurements and CFD

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Abstract

The newly implemented vortex code *Omnivor [8],* coupled to the aero-servo-elastic tool *hawc2 [7],* is presented. Vortex wake improvements by the implementation of viscous effects are considered.

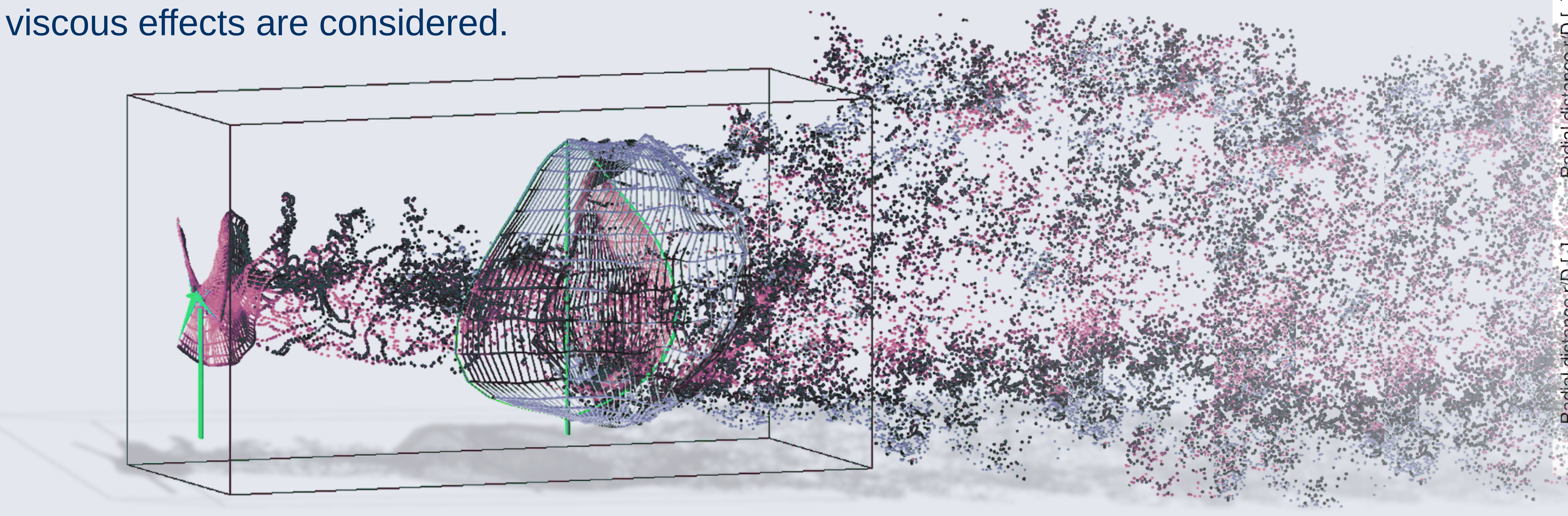


Figure 1: Vortex-based aeroelastic simulation of the *Deepwind* vertical axis wind turbine in the wake of a horizontal axis turbine. Nacelle and tower modeled with source panels. Conversion from vortex segments to particles. The frame represents the *hybrid-wake* grid [6] that will be used to record the influence of the far-wake.

Description of the vortex code and viscous models

- Convection/Strain/Diffusion as separate steps [5]
- Elements: segments, particles, panels and misc.: theoretical elements(rings, cylinders, helices), Lagrangian markers. See Figs. 1 and 2.
- Lifting(line, surface, panels) and non-lifting (source) bodies. Viscous boundary condition for non lifting bodies (beta version)
- Wake viscous models tested: grid-based, random-walk, core-spreading (to do: particle-strength-exchange)
- Strong/Soft coupling with *hawc2*
- Acceleration: clusters or GPU

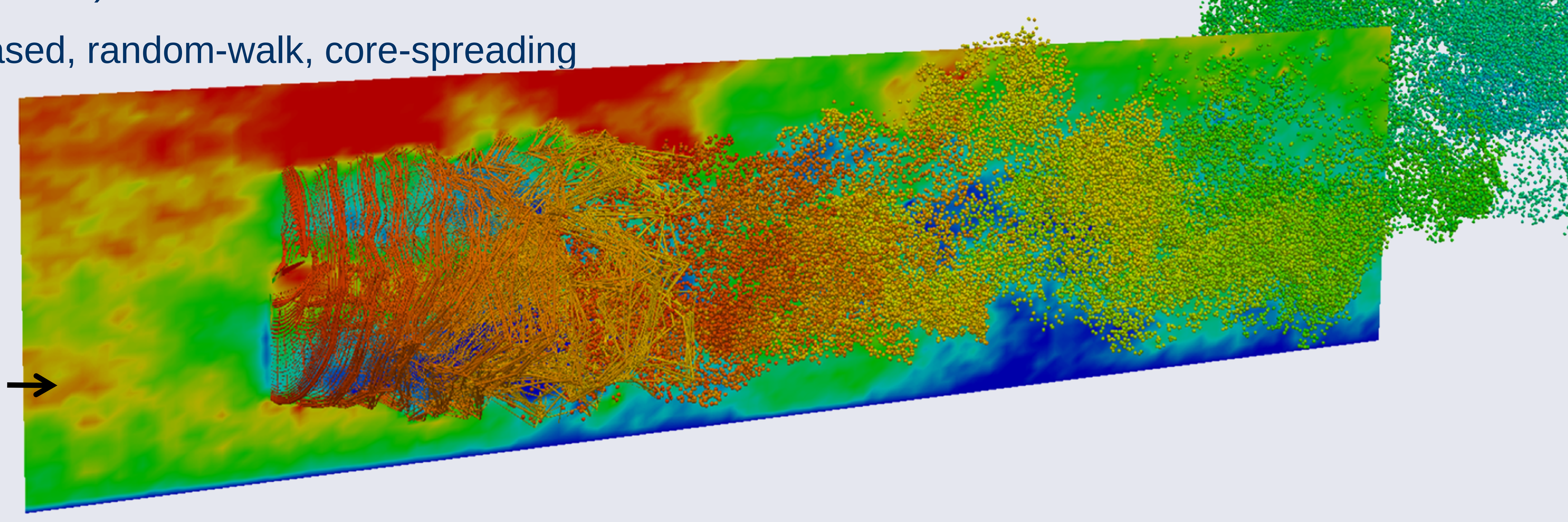


Figure 2: Vortex-based aeroelastic simulation of the *Nordtank* turbine with *hawc2* and *Omnivor*. Strained vortex segments are converted to particles. Shear and turbulent inflow are used but they are external to the "potential flow world".

Laminar inflow – Viscous models

Figure 5: Comparison between CFD (top) and vortex code (bottom) axial velocity contours normalized with free –stream velocity. The vortex wake do not sustain the deficit as far downstream as the CFD simulation.

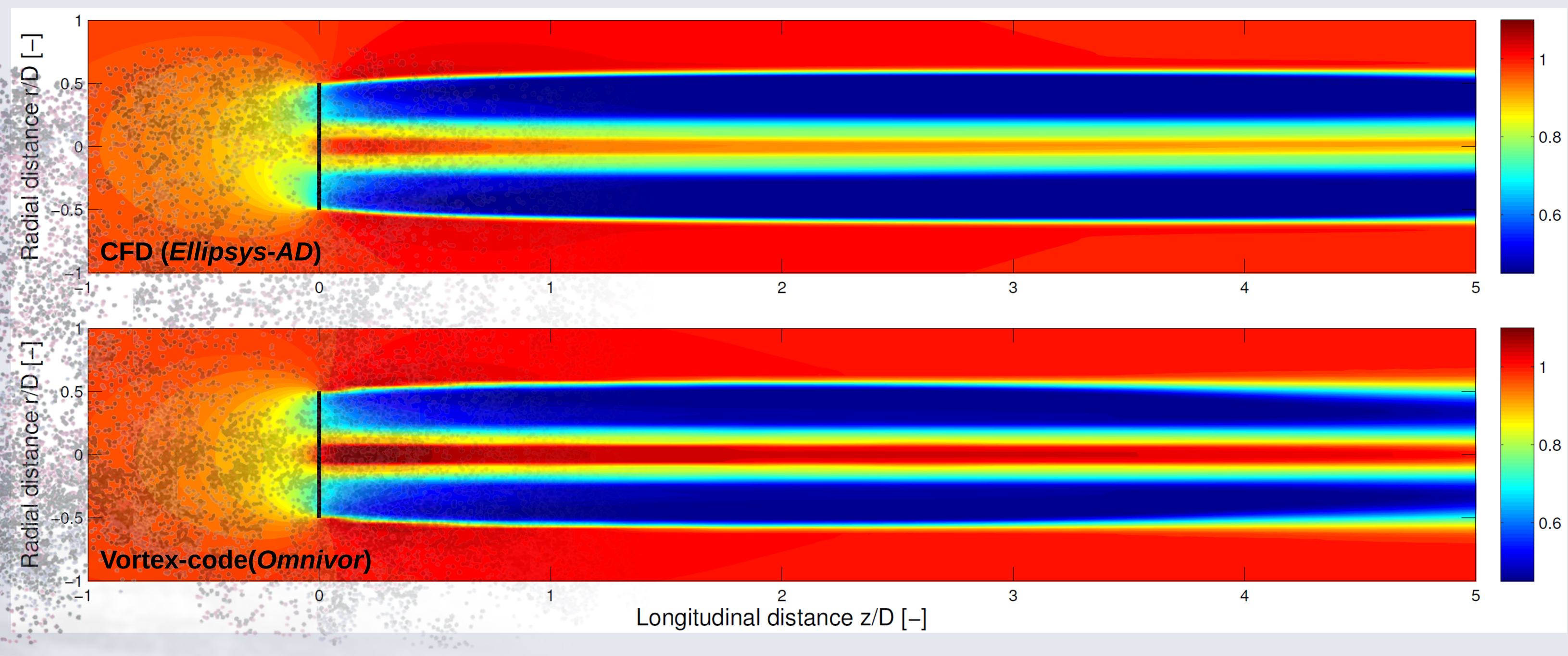


Figure 6: 10min-average wake deficits for two viscosity values. Comparison of CFD and vortex code, and two vortex code viscous models. Strong correlation in the near wake. Trend captured: wake deficit reduced for increased vorticity. Differences in the far-wake may be due to wake distortion (no resampling).

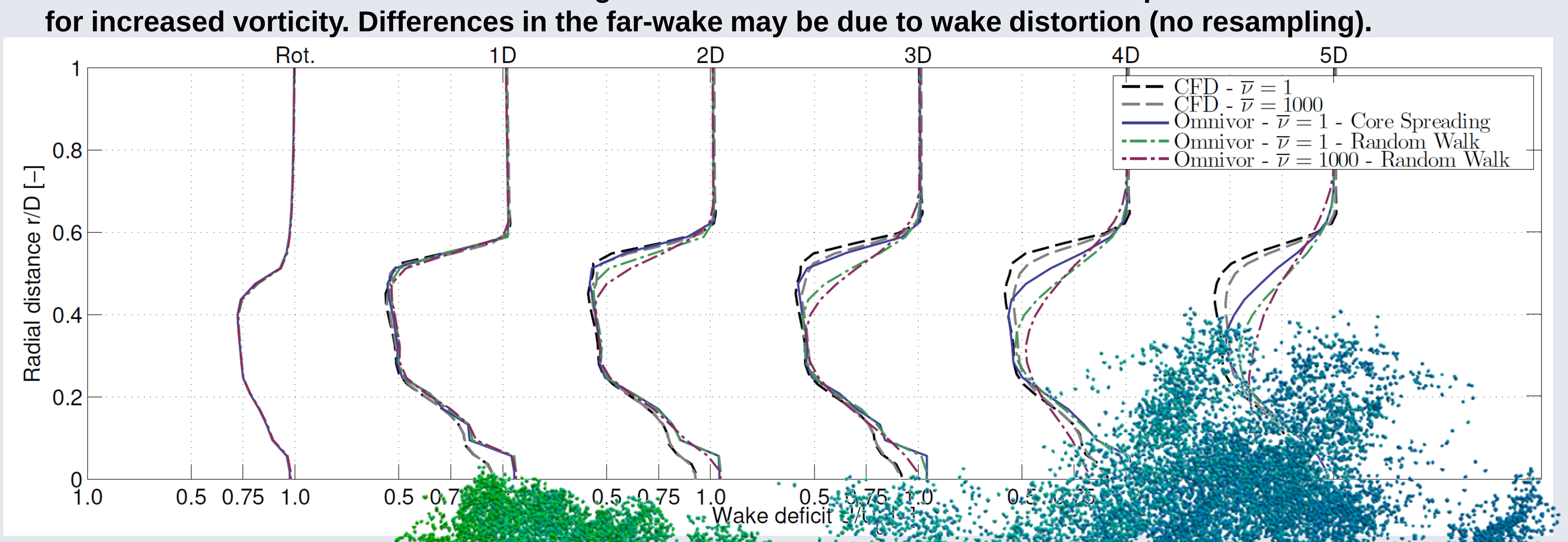


Figure 7: Uniform-inflow ("laminar") simulation revealing instabilities occurring in the far wake. Similar instabilities were observed in the CFD computations but further downstream.

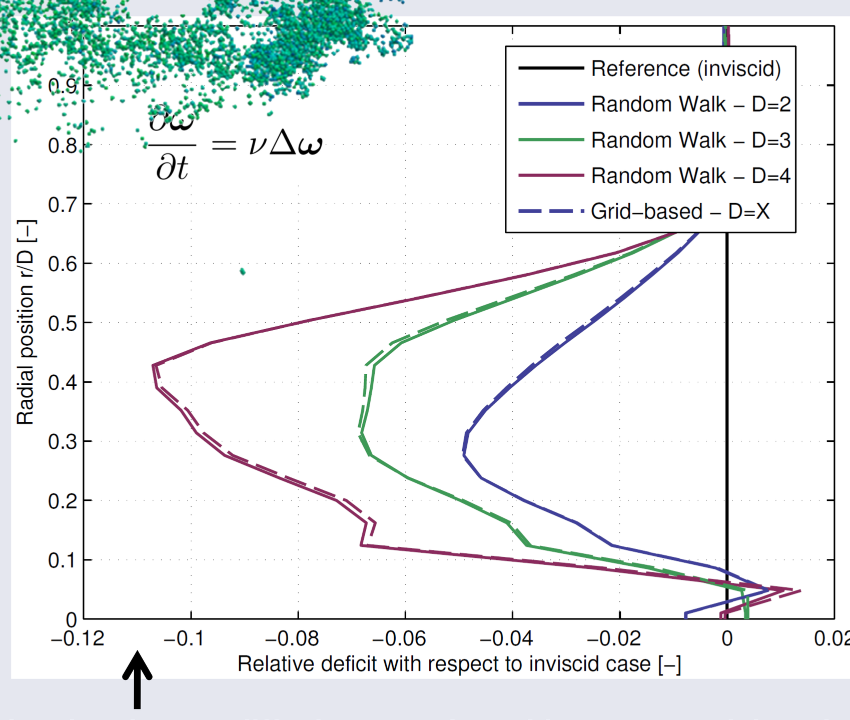
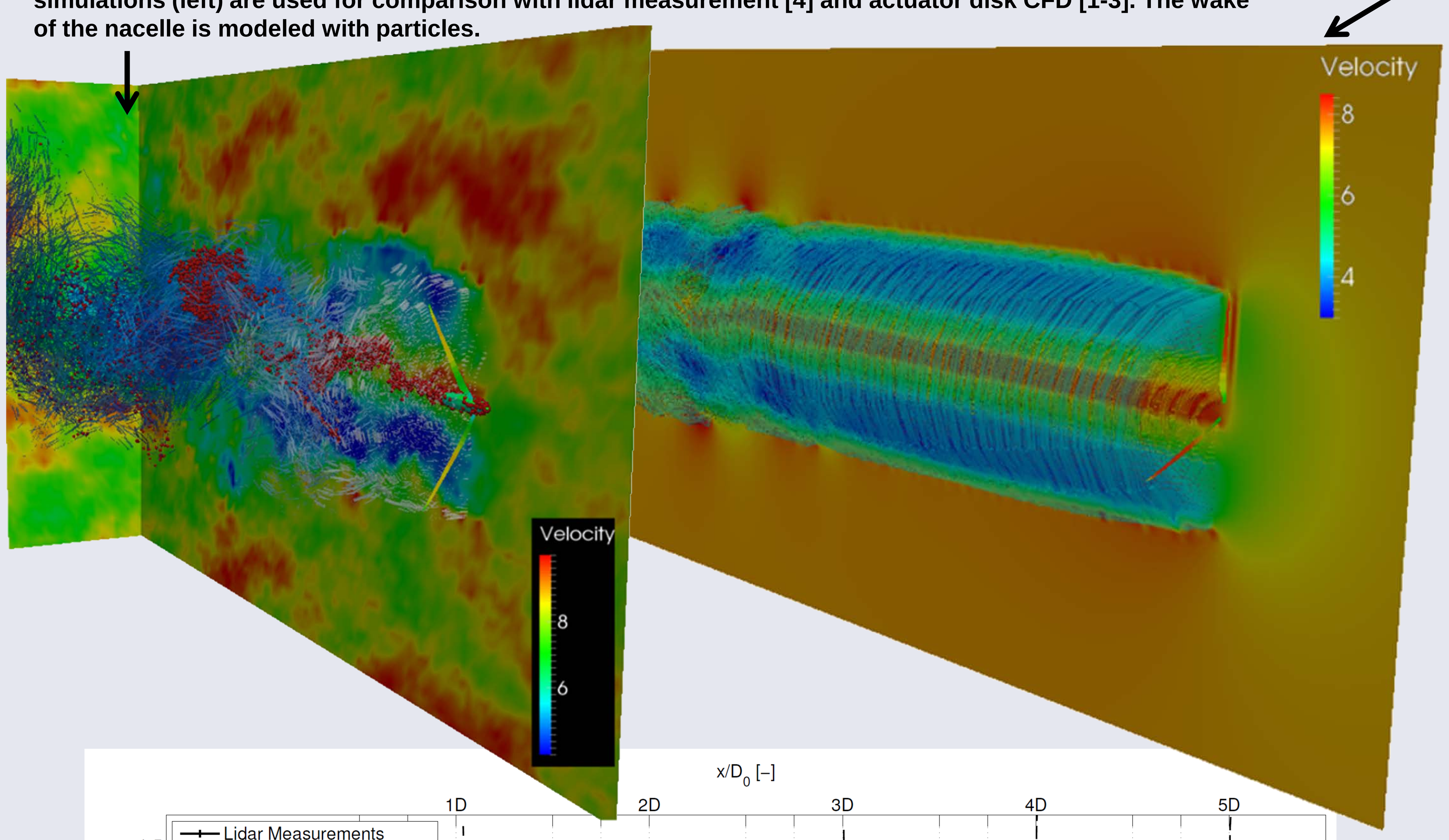


Figure 8: Comparison of two ways to solve the viscous diffusion equation with vortex particles: the random walk method and the grid-based (finite difference) method. The average wake deficits obtained with the two methods are in strong agreement. This validates the random walk approach.

Turbulent inflow : Lidar measurements, Vortex Code and CFD

Figure 3: Velocity field and potential flow elements for typical 10-min vortex-code simulations . Turbulent simulations (left) are used for comparison with lidar measurement [4] and actuator disk CFD [1-3]. The wake of the nacelle is modeled with particles.



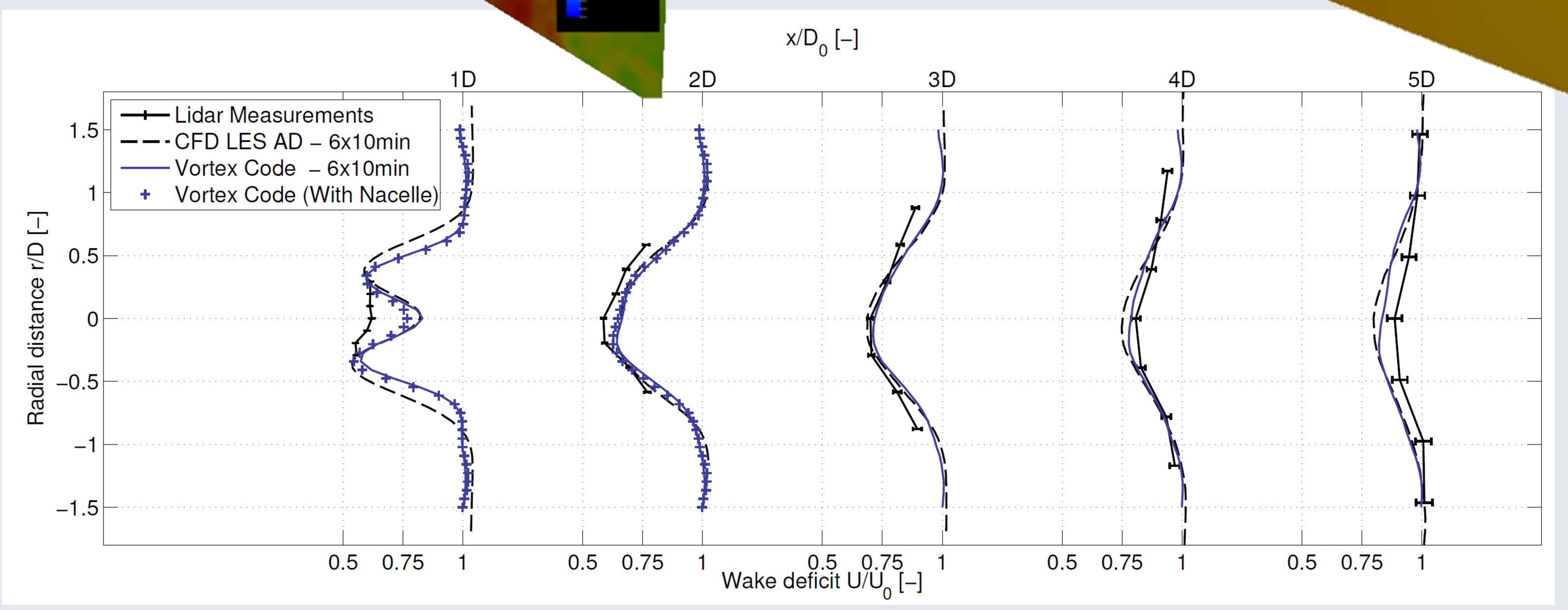


Figure 4: One-hour wake deficits behind the *Nordtank* turbine. Comparisons between lidar measurements, CFD and vortex code. Preliminary nacelle modeling shows slight improvement but a better modeling of the nacelle and its wake is required for both the CFD-AD/AL and the vortex code to capture the near-wake.

Conclusions

- A new vortex-based aerodynamic library implemented.
- The library was successfully coupled to the aero-servo-elastic tool *hawc2.*
- For turbulent and laminar inflow, CFD and vortex code showed consistent results up to 3 diameters downstream
- External turbulence and shear appeared sufficient to obtain agreement with lidar measurement and CFD. Potential-flow implementations would be preferred.
- Viscous effects down to $Re_D = 2x10^4$ are negligible in the near wake. The modeling of the nacelle is important.
- Consistent results between grid-based viscous diffusion and random-walk
- Core-spreading to be used with care (tuning required)
- Further work: further viscous validations (at low Re), more advanced body-viscosity model, improved far-wake modeling

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